On Transport Layer Adaptation in Heterogeneous Wireless Data Networks

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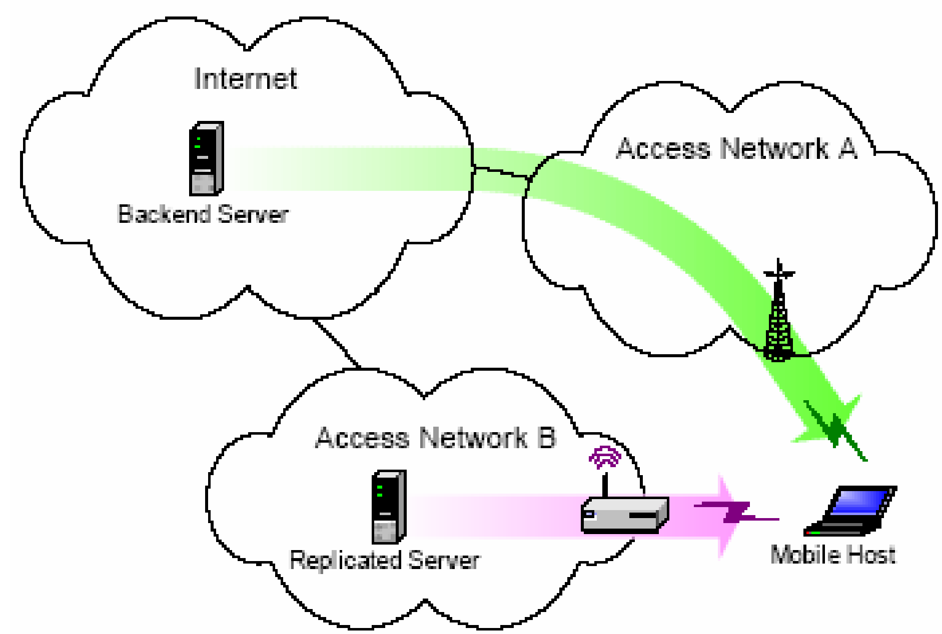
Heterogeneous Wireless Networks

- Mobile users desire ubiquitous access to information
- Mobile hosts are equipped with heterogeneous wireless interfaces
- Performance tradeoffs
  - Network capacity, coverage area, mobility support, and transmission power
- Challenges
  - Varied network characteristics in terms of bandwidth, delay, loss rate, and bandwidth fluctuation
- Objective
  - Achieving best performance in any given wireless network



Overview

- Current Transport Solutions
  - Target specific wireless network conditions
- Transport Adaptation
  - What is transport adaptation?
  - Ideal nature of transport adaptation
  - Ideal time granularity of transport adaptation
- *TP : Runtime Adaptive Transport Layer Framework
  - Design
  - Framework
- Performance Evaluation
  - Show the effect of adaptation in heterogeneous wireless networks
- Summary

Current transport solutions

- Alternative mechanisms to the de-facto standard transport protocol, TCP
- TCP-ELN
  - Addresses the issue of high loss rates in Wireless Local Area Networks (WLANs)
  - Uses explicit loss notification to perform intelligent congestion detection
  - Suffers under very high loss rates
- WTCP
  - Solves the problem of high loss rates in Wireless Wide-Area Networks (WWANs)
  - Uses inter-packet separation as the indicator of congestion
  - Suffers under low delay and high jitter conditions
- STP
  - Addresses the issue of asymmetric nature of satellite links
  - Uses polled acknowledgement scheme to reduce reverse path bandwidth consumption

Current transport solutions

	TCP-ELN	WTCP	STP
WLAN	✓	Suffers due to significant jitter condition	Unable to determine forward path bandwidth
WWAN	Suffers due to high loss	✓	Unable to determine forward path bandwidth
Satellite network	High reverse path overhead	High reverse path overhead	✓

Adaptation at transport layer

- How to address the specific characteristics of heterogeneous wireless networks?
- Perform adaptation at the transport layer
- Transport Adaptation
  - Behavior of a transport protocol with the goal of obtaining best performance when a mobile host moves across different wireless networks
- Ideal nature of transport adaptation
  - **What** should be changed within the transport layer for achieving optimal performance?
- Ideal time granularity for transport adaptation
  - **When** should adaptation be performed for achieving optimal performance?

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Nature of transport adaptation

- **What** should be changed within the transport layer for achieving optimal performance?
- Options
  - Entire transport protocol
  - Transport layer mechanisms
  - Transport protocol parameters
- Observations
  - Network conditions impact the performance of transport mechanisms
  - High wireless loss rate (network condition) adversely affects loss-based congestion detection mechanism (transport mechanism)
  - Window-based congestion control (transport mechanism) used by the same transport protocol (TCP) is not affected by high loss rate
  - Increasing the number of SACK blocks (protocol parameter) is not sufficient to overcome high wireless loss rate

☛ Transport adaptation should be performed at the granularity of **transport layer mechanisms**

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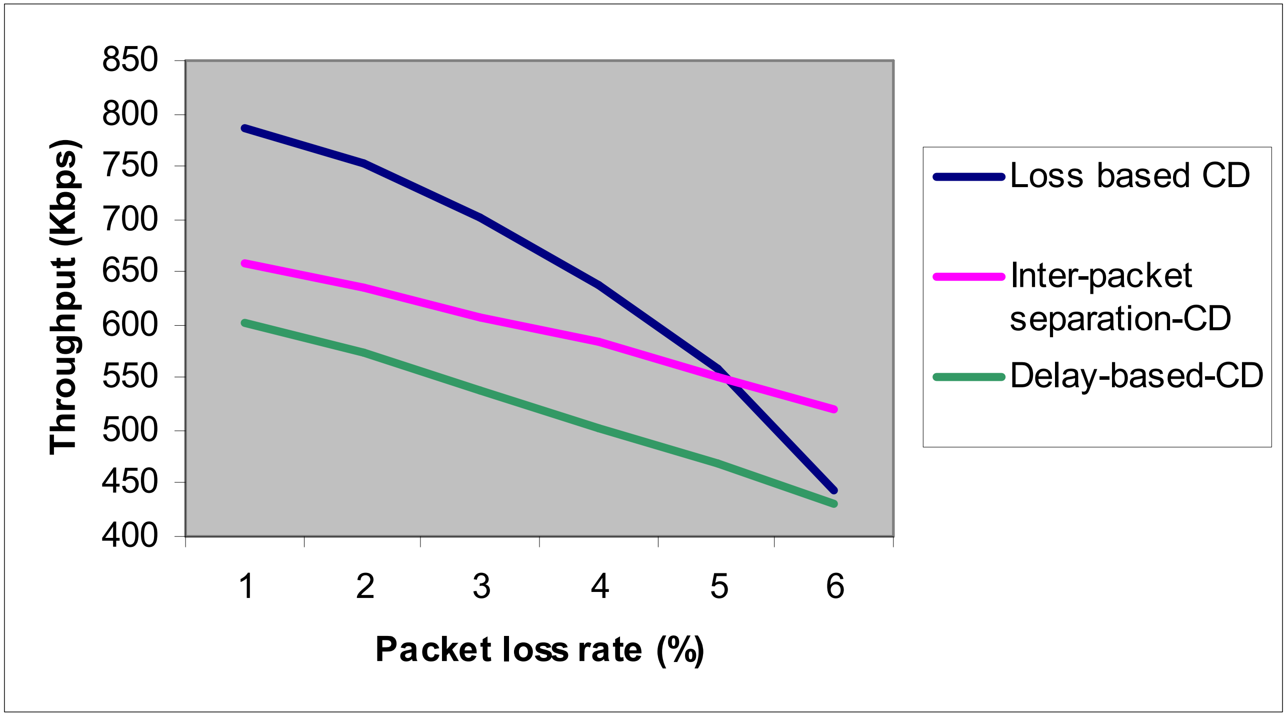
Nature of transport adaptation



Time granularity of transport adaptation

- **When** should adaptation be performed for achieving optimal performance?
- Options
  - Transport layer sessions
  - Wireless interface handoffs
  - Network characteristic change
- Observations
  - Network conditions impact the performance of transport mechanisms
  - Performance of inter-packet separation based congestion detection is affected at high jitter conditions
  - Network conditions can change within the same wireless access network
  - Delay variations (jitter) can be high even within a WWAN depending on the amount of multiplexing of other traffic that is performed at the base station
- Transport layer adaptation should be performed when **network characteristics change**

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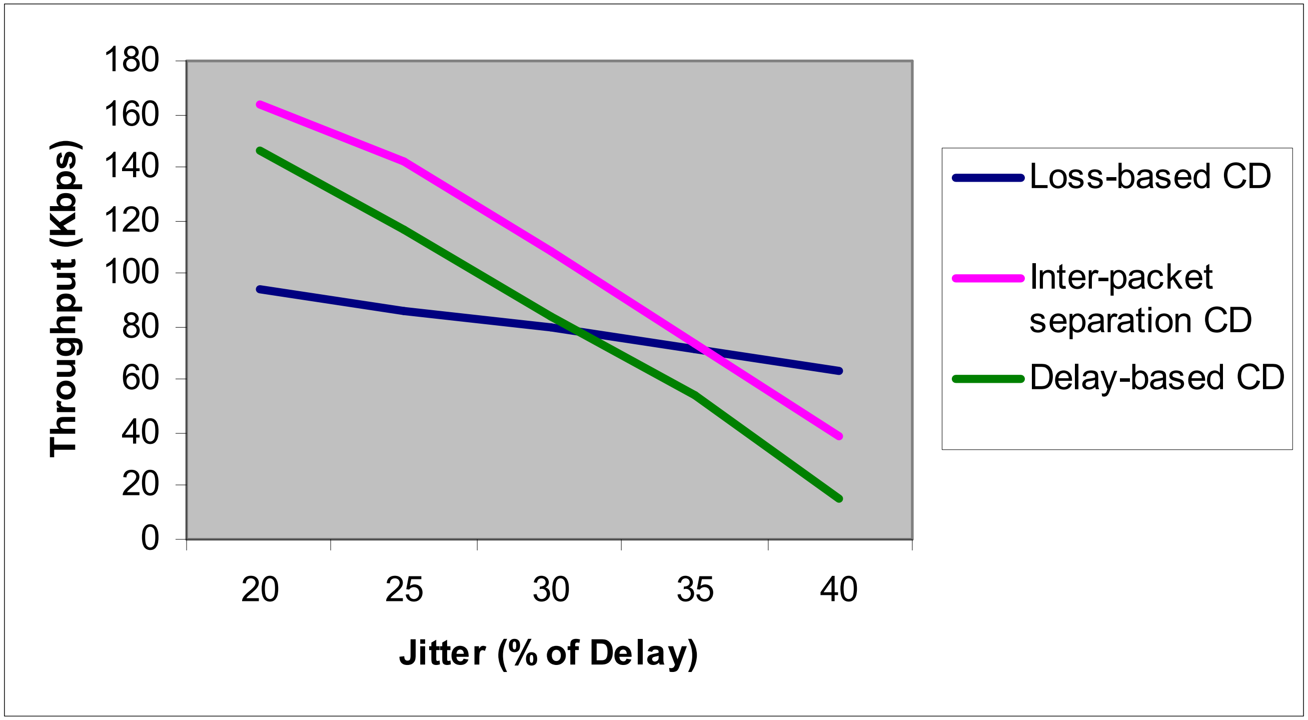
Time granularity of transport adaptation



*TP : Design Goals

- **Reconfigurability**
  - Ability to use transport layer mechanisms best-suited for the given environment
  - Ability to perform reconfiguration at runtime, triggered by changes in network characteristics
  - Ability to perform reconfiguration in an application unaware fashion
- **Extensibility**
  - Operation should not be limited by specific transport protocol or mechanism
  - Should be able to accommodate any transport mechanism, potentially those that may be developed in future
- **Minimal Overheads**
  - Overheads comparable to static transport protocols
  - Execution efficiency, redundancy due to repetitive functionality implementation, reconfiguration latency
- **Easy deployability**
  - Should be able to be deployed in an incremental fashion in current network architecture

Design elements

- **Separation of core and non-core modules**
  - Transport layer framework constitute the core
  - Transport mechanisms form the non-core
  - ✓ Helps in reconfigurability and minimizing overheads
- **Triggers**
  - Identify network condition changes
  - Enable reconfiguration of transport mechanism
  - ✓ Helps in reconfigurability
- **Modular architecture and execution model**
  - Non-core components are designed to be modular
  - Enables fast-swapping and fine-grained adaptation of transport mechanisms
  - ✓ Helps in minimizing overheads

Design elements

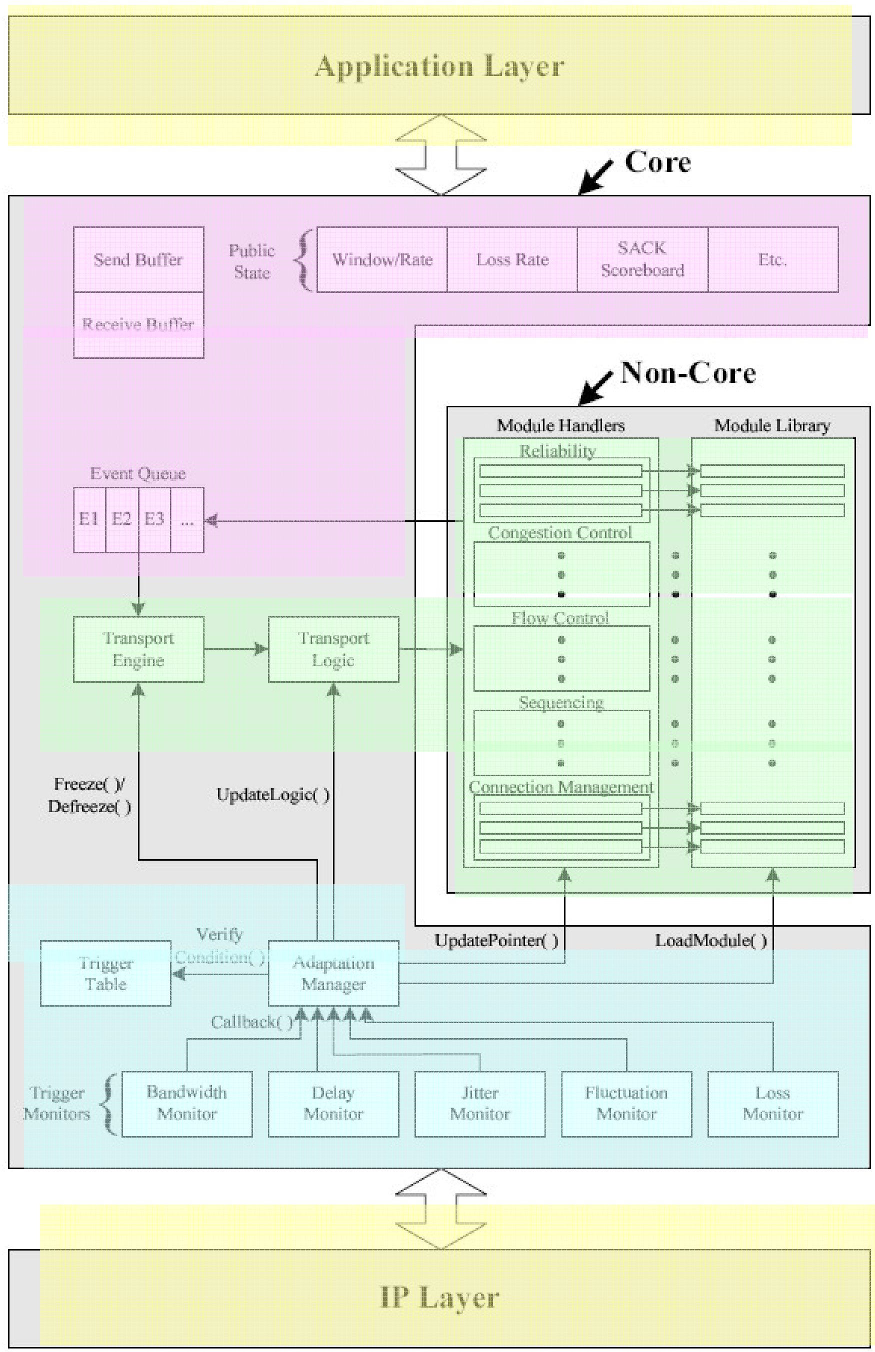
- **State Propagation**
  - Inheritance of transport layer state across non-core modules
  - Helps in extensibility and reconfigurability
- **Mobile-host centric operations**
  - Reconfiguration happens at the mobile host
  - Static Internet host *TP configuration need not change
  - Facilitates deployability

*TP Software Architecture

- **Transport engine**
  - Logic for the execution of the transport mechanisms which are event handlers
  - Transport mechanisms respond to external events and events generated by other modules
  - Transport engine executes the transport logic which specifies how the transport mechanisms are used
- **Reconfiguration entities**
  - Aid in the reconfiguration process
  - Trigger table is logical combination of network parameters monitored by the trigger monitor
  - Adaptation manager receives callbacks from the trigger monitors when the conditions specified by non-core modules are satisfied
  - Adaptation manager then loads the corresponding modules into the non-core

*TP Software Architecture

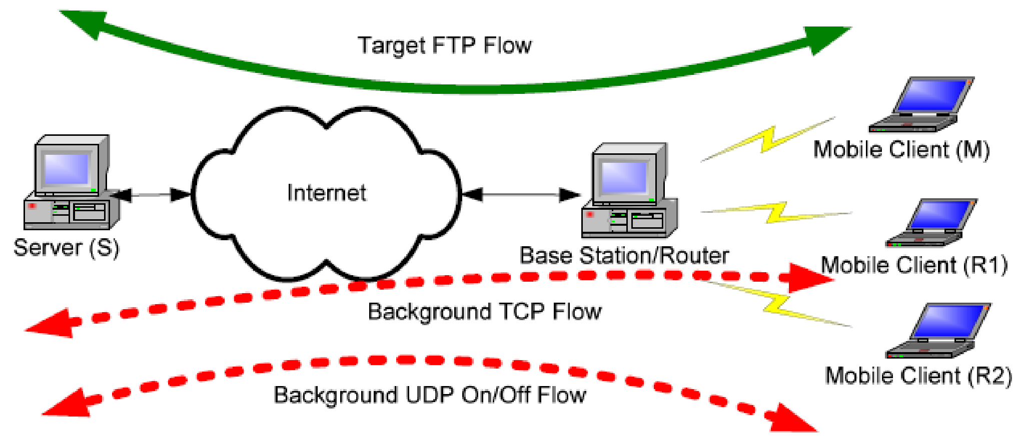
- **Interface with the Application and IP layers**
  - Core provides a fixed interface for the application layer and the IP layer
  - Socket layer abstraction maintained
  - ✓ Helps in application and network independent manner
- **Global Data Structures**
  - Common data repository for transport mechanisms
  - Send and receive buffers
  - Event queue
  - ✓ Facilitates state inheritance
  - ✓ Serves as a shared space for non-core modules (transport mechanisms) to communicate with each other



Application Layer
Core
Send Buffer
Receive Buffer
Public State
Window/Rate
Loss Rate
SACK Scoreboard
Etc.
Non-Core
Module Handlers
Module Library
Reliability
Congestion Control
Flow Control
Sequencing
Connection Management
Event Queue
E1
E2
E3
...
Transport Engine
Transport Logic
Freeze( )/ Defreeze( )
UpdateLogic( )
UpdatePointer( )
LoadModule( )
Verify Condition( )
Trigger Table
Adaptation Manager
Callback( )
Trigger Monitors
Bandwidth Monitor
Delay Monitor
Jitter Monitor
Fluctuation Monitor
Loss Monitor
IP Layer

Performance study

- Connection between server and access router spans 16 Internet hops
- Protocols used
  - TCP-ELN
  - WTCP
  - STP
- Last hop from access router to mobile host is WLAN connection
- WWAN and satellite network are emulated by altering the characteristics of the wireless link
- Packet loss rates are emulated by inserting a random loss module at the router



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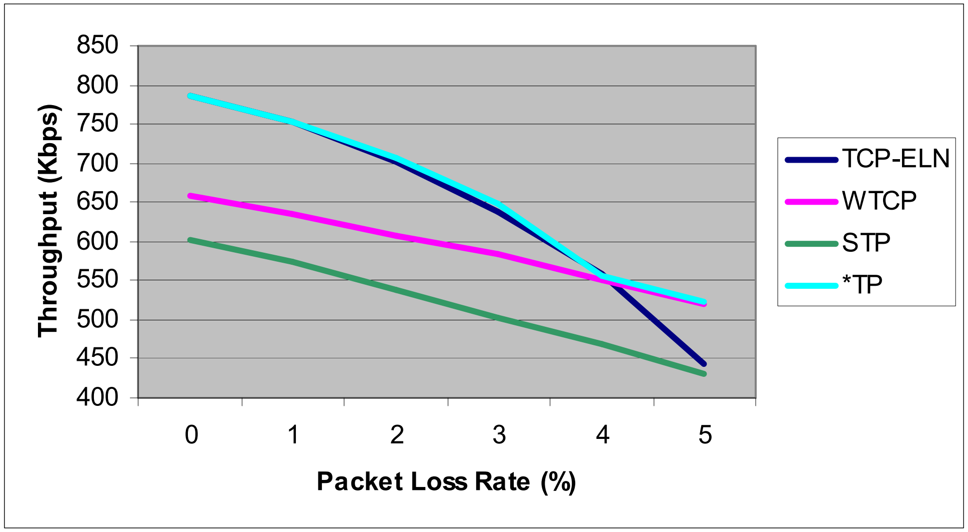
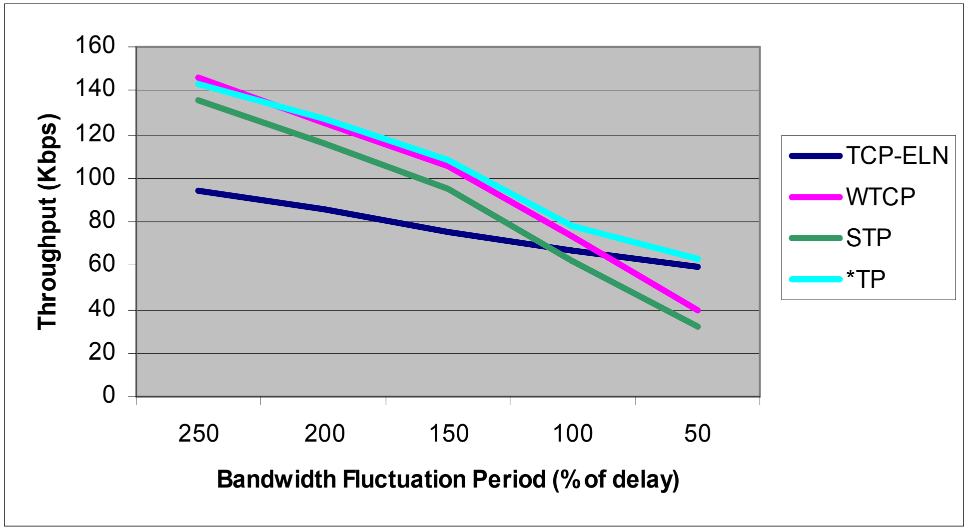
Lossy WLANs

- Loss-based congestion detection suffers at high loss-rates
- Insufficient information about the network at high packet loss rates
- Loss-rate as the trigger parameter for the loss-based congestion detection mechanism
- *TP adapts to achieve optimal performance across different packet loss rate



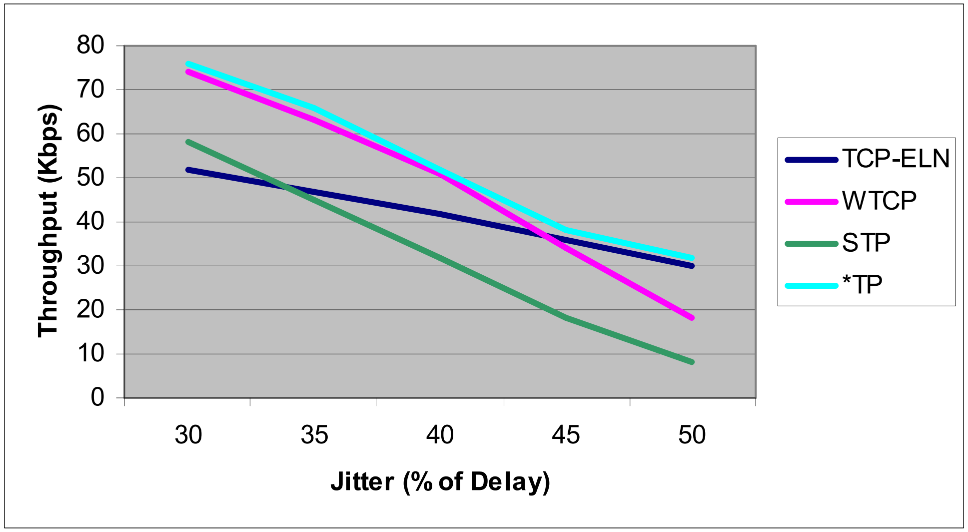
Bandwidth Fluctuation in WWAN

- Tuned acknowledgment scheme used by WTCP suffers when the bandwidth fluctuation increases
- *TP can accommodate both the tuned rate acknowledgment and self-clocked acknowledgment mechanisms
- *TP is able to adapt the acknowledgment mechanism for optimal performance even as the bandwidth fluctuation increases



Jitter in Satellite Networks

- Delay and inter-packet separation based congestion detection mechanisms suffer under high delay variations
- Under high jitter conditions in satellite networks *TP is able to change the congestion detection mechanism from delay-based to loss-based and achieve optimal performance



Summary

- Problem of transport adaptation in heterogeneous wireless data networks
- Ideal nature of transport adaptation
- Ideal time granularity of transport adaptation
- Design and implementation of *TP
- For more information:
    - http://www.ece.gatech.edu/research/GNAN